

Introduction to *The Supersymmetric World: The Beginnings of The Theory*

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This is the foreword to the book we edited on the origins and early development of supersymmetry, which has been just issued by World Scientific. This book presents a view on the discovery of supersymmetry and pioneering investigations before summer 1976, mainly in the words of people who participated. It combines anecdotal descriptions and personal reminiscences with more technical summaries of the trailblazers, covering the birth of the theory and its first years—origin of the idea, four-dimensional field theory realization, and supergravity. The eyewitnesses convey to us the drama of one of the deepest discoveries in theoretical physics in the 20th century. Contributors: V. Akulov, R. Di Stefano, P. Fayet, S. Ferrara, G.-L. Gervais, N. Koretz-Golfand, E. Likhtman, M. Marinov, A. Neveu, L. O’Raifeartaigh, P. Ramond, B. Sakita, J. Schwarz, M. Sohnius, V. Soroka, J. Strathdee, D. Volkov, J. Wess, P. West.

The history of supersymmetry is exceptional. All other major conceptual developments in physics and science have occurred because scientists were trying to understand or study some established aspect of nature, or to solve some puzzle arising from data. The discovery of supersymmetry in the early 1970’s, an invariance of the theory under interchange of fermions and bosons, was a purely intellectual achievement, driven by the logic of theoretical development rather than by the pressure of existing data. Thirty years elapsed from the time of discovery, immense theoretical effort was invested in this field, over 30,000 papers published. However, none of them can claim to report the experimental discovery of supersymmetry (although there are some hints, of which we will say more later). In this respect the phenomenon is rather unprecedented in the history of physics. Einstein’s general relativity, the closest possible analogy one can give, was experimentally confirmed within several years after its creation. Only in one or two occasions have theoretical predictions of a comparable magnitude had to wait for experimental confirmation that long. For example, the neutrino had a time lag of 27 years.

It would not be an exaggeration to say that today supersymmetry dominates theoretical high energy physics. Many believe that it will play the same revolutionary role in the physics of the 21st century as special and general relativity did in the physics of the 20th century. This belief is based on aesthetical appeal, on indirect evidence, and on the fact that no theoretical alternative is in sight.

The discovery of supersymmetry presents a dramatic story dating back to the late 1960's and early '70's. For young people who entered high energy physics in the 1990's this is ancient history. Memories fade away as live participants of these events approach the retirement age; some of them have already retired and some, unfortunately, left this world. Collecting live testimonies of the pioneers, and preserving them for the future, seems timely given the impact supersymmetry has already produced on the development of particle physics. Having said that, we note that this book did not appear as a result of a conscious project. Both editors had collected some materials for other activities^{1,2} and became aware of the other's interest and materials. Many people have been interested in how supersymmetry originated—the question often is asked in informal conversations—and how it can be such an active field even before direct experimental confirmation. We finally decided to combine materials, invite further ones, and edit this volume that makes available a significant amount of information about the origins of this intellectually exciting area. Most of it is in the words of the original participants.

In the historical explorations of scientific discoveries (especially, theoretical) it is always very difficult to draw a “red line” marking the true beginning, which would separate “before” and “after.” Almost always there exists a chain of works which interpolates, more or less continuously, between the distant past and the present. Supersymmetry is no exception, the more so because it has multiple roots. It was observed as a world-sheet two-dimensional symmetry^a in string theories around 1970; at approximately the same time Golfand and Likhtman found the superextension of the Poincaré algebra and constructed the first four-dimensional field theory with supersymmetry, (massive) quantum electrodynamics of spinors and scalars. Within a year Volkov and collaborators (independently) suggested nonlinear realizations of supersymmetry and started the foundations of supergravity. Using the terminology of the string practitioners one can say that the first supersymmetry revolution occurred in 1970-71 as the idea originated.^b The second supersymmetry revolution came

^aThe realization that the very same string theories gave rise to supersymmetry in the target space came much later.

^bIn the Marxist terminology it would be more exact to say that this was a prerevolutionary situation. This nuance is too subtle, however, and cannot be adequately discussed in this

with the work of Wess and Zumino in 1973. Their discovery of linearly realized supersymmetry in four dimensions opened to the rest of the community the gates to the Superworld. The work on supersymmetry was tightly woven in the fabrique of contemporary theoretical physics. During the first few years of its development, there was essentially no interest in whether or how supersymmetry might be relevant to understanding nature and the traditional goals of physics. It was “a solution in search of a problem.” Starting in the early 1980’s, people began to realize that supersymmetry might indeed solve some basic problems of our world. This time may be characterized as the third supersymmetry revolution.

So, how far in the past should one go and where should one stop in the book devoted to the beginnings?

The above questions hardly have unambiguous answers. We decided to start from Ramond, Neveu, Schwarz, Gervais, and Sakita whose memoirs are collected in the chapter entitled *The Predecessors*, which opens the book. The work of these authors can be viewed as precursive to the discovery of supersymmetry in four dimensions. It paved the way to Wess and Zumino.

Chapter 2 presenting *The Discovery* is central in the first part of the book. It contains recollections of Likhtman, Volkov, Akulov, Koretz-Golfand (Yuri Golfand’s widow) and the 1999 Distinguished Technion Lecture of Prof. J. Wess, in which the basic stages of the theoretical construction are outlined. Chapter 3 is devoted to the advent of supergravity. The fourth chapter is entitled *The Pioneers*. The definition of pioneers (i.e. those who made crucial contributions at the earliest stage) is quite ambiguous, as is the upper cut off in time which we set, *the summer of 1976*. By that time no more than a few dozen of original papers on supersymmetry had been published.

The selection of the contributors was a difficult task. For various reasons we were unable to give floor to some theorists who were instrumental at the early stages (e.g. R. Arnowitt, L. Brink, R. Delbourgo, P.G.O. Freund, D.R.T. Jones, J.T. Łopuszański, P. Nath, Y. Ne’eman, V.I. Ogievetsky, A. Salam, E. Sokatchev, B. de Wit). Some are represented in other chapters (e.g. S. Ferrara whose 1994 Dirac Lecture is being published in Chap. 3.) Others are beyond reach. This refers to Abdus Salam and Victor Ogievetsky. The latter, by the way, wrote (together with L. Mezincescu) the first comprehensive review on supersymmetry which was published in 1975.³ Even now it remains an excellent introduction to the subject, in spite of the 25 years that have elapsed.

The question of where to draw the line tortured us, and we bring our apologies to all the pioneers who “fell through the cracks.”

article.

The second part of the book is an attempt to present a historical perspective on the development of the subject. This task obviously belongs to the professional historians of science; the most far-sighted of them will undoubtedly turn their attention to supersymmetry soon. For the time being, however, to the best of our knowledge, there are no professional investigations on the issue. There was available a treatise written by Rosanne Di Stefano in 1988 for a conference proceedings which were never published. This is a very thorough and insightful review. On the factual side it goes far beyond any other material on the history of supersymmetry one can find in the literature. There are some omissions, mostly regarding the Soviet contributors, which are naturally explained by the isolation of the Soviet community before the demise of the USSR and relative inaccessibility of several key papers written in Russian. The Yuri Golfand Memorial Volume² which contains the English translation of an important paper by Golfand and Likhtman⁴ as well as a wealth of other relevant materials, fills the gap. In addition, Springer-Verlag has recently published Memorial Volumes in honor of Dmitry Volkov⁵ and Victor Ogievetsky,⁶ which acquaint the interested reader with their roles to a much fuller extent than previously.

The coverage of certain physics issues in Di Stefano's essay required comment; in a few cases we added explanatory footnotes. Di Stefano's essay is preceded by a relatively short article written by the late Prof. Marinov. It is entitled "Revealing the Path to the Superworld" and was originally intended for the Golfand Volume. This article presents "a bird's eye view" on the area. On the factual side it is much less comprehensive than Di Stefano's, but it carries a distinctive flavor of the testimony of an eye witness. Moreover, it reveals the mathematical roots of the discovery, an issue which is only marginally touched in Di Stefano's essay.

We are certainly not professional historians of science; still we undertook a little investigation of our own. Often students ask where the name "supersymmetry" came from? It seems that it was coined in the paper by Salam and Strathdee⁷ where these authors constructed supersymmetric Yang-Mills theory. This paper was received by the editorial office on June 6, 1974, exactly eight months after that of Wess and Zumino. Super-symmetry (with a hyphen) is in the title, while in the body of the paper Salam and Strathdee use both, the old version of Wess and Zumino, "super-gauge symmetry," and the new one. An earlier paper of Ferrara and Zumino⁸ (received by the editorial office^c on May 27, 1974) where the same problem of super-Yang-Mills was addressed, mentions only supergauge invariance and supergauge transformations.

^cThe editorial note says it was received on May 27, 1973. This is certainly a misprint; otherwise, the event would be acausal.

Supersymmetry is nearly thirty years old. It seems that now we are approaching the fourth supersymmetry revolution which will demonstrate its relevance to nature. Although not numerous, we do have hints that this is the case. They are: (a) supersymmetry allows a stable hierarchy between the weak scale and the shorter distance scales such as the Planck scale or unification scale, (b) supersymmetry provides a way to understand how the electroweak $SU(2) \times U(1)$ symmetry is broken, so long as the top quark came out heavy (which it did), (c) gauge couplings unify rather accurately when superpartners are included in the loops,^d(d) the Higgs boson is predicted to be light (LEP gives $M_H < 200$ GeV), and (e) the lack of any deviations from Standard Model predictions in the precision data at LEP and in other experiments is consistent with supersymmetry (it was anticipated that these deviations would be invisible).

Certainly, at the moment the indications are not conclusive. However inconclusive, they are the source of hope and enthusiasm for phenomenologically oriented theorists and experimentalists who would like to keep high-energy physics in the realm of empirical science.

Another aspect which came to limelight recently is the fact that supersymmetry became instrumental in the solution of highly nontrivial dynamical issues in strongly coupled non-supersymmetric theories, which defied solutions for decades. That of course does not imply that nature is supersymmetric, but it does add to the interest in supersymmetry.

Summarizing, in this book we bring together contributions from many of the key players of the early days of supersymmetry. We leave its relevance to our world to a future project.

References

1. G. Kane, *Supersymmetry: Unveiling the Ultimate Laws of Nature* (Perseus Books, 2000).
2. *The Many Faces of the Superworld*, Yuri Golfand Memorial Volume, Ed. M. Shifman (World Scientific, Singapore, 2000).
3. V.I. Ogievetsky, and L. Mezincescu, *Usp. Fiz. Nauk* **117**, 637 (1975), [*Sov. Phys. - Uspekhi* **18**, 960 (1975)].
4. Yu.A. Golfand and E.P. Likhtman, *On the Extensions of the Algebra of the Generators of the Poincaré Group by the Bispinor Generators*, in I. E. Tamm Memorial Volume *Problems of Theoretical Physics*, Eds. V.L.

^dAn alternative way to say this is to say that the value of the weak mixing angle at the weak scale can be calculated accurately if one sets it to the value predicted by a unified theory at the unification scale.

- Ginzburg *et al.*, (Nauka, Moscow, 1972), page 37 [English translation: Ref. 2, page 45].
5. *Supersymmetry and Quantum Field Theory*, Proceedings of the D. Volkov Memorial Seminar, Kharkov, Ukraine, January 1997 [Lecture Notes in Physics, Vol. 509], Ed. J. Wess and V. Akulov, (Springer-Verlag, 1998).
 6. *Supersymmetries and Quantum Symmetries*, Proceedings of the International Seminar on Supersymmetries and Quantum Symmetries Dedicated to the Memory of V.I. Ogievetsky, Dubna, Russia, July 1997 [Lecture Notes in Physics, Vol. 524] (Springer-Verlag, 1999).
 7. A. Salam and J. Strathdee, “Super-symmetry and non-Abelian gauges”, *Phys. Lett. B* **51**, 353 (1974).
 8. S. Ferrara and B. Zumino, “Supergauge invariant Yang-Mills theories”, *Nucl. Phys. B* **79**, 413 (1974).

Related Materials

Proceedings of the Symposium *Thirty Years of Supersymmetry*, Minneapolis, October 13-15, 2000, Ed. by K. Olive, S. Rudaz, and M. Shifman (North Holland, 2001).

Thirty Years of Supersymmetry, in Theoretical Physics Institute Newsletter # 2, <http://www.tpi.umn.edu/Issue2.pdf>.

E. Likhtman, *Around SuSy 1970*, Talk at the Symposium *Thirty Years of Supersymmetry*, Minneapolis, October 13-15, 2000, hep-ph/0101209.